Project Description/Summary of "Modeling the Air Traffic Over the North Atlantic Ocean"

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Overall Project Plan/Approach:

The overall goals of this project is to create a tool to determine the safety, efficiency, communication, and system flexibility considerations of the North Atlantic air traffic in view of proposed system changes, such as changes in separation standards, traffic mixes, and communication systems. The approach is to create a simulation model based on the existing air traffic system in the North Atlantic. This model will utilize a fast time simulation language, General Purpose Simulation Language (GPSS). The simulation model will represent the essential characteristics of the system to generate statistics of performance of the parameters described above, such as safety, efficiency, etc.. These statistics will be in the form of detailed hard copy reports and also graphical animation.

The first step in building any effective model is understanding and documenting the *essential* characteristics of the system[1] . Essential characteristics are the elements of the system that will effect the outcome on the system parameters under study. It would not be efficient or practical to build a model detailing all the characteristics of the system, especially a complex system such as the North Atlantic air traffic system. To gain understanding of these essential characteristics, we first study the system by gathering or collecting statistical data. This step may also be enhanced by reviewing the accomplishments of other similar models. In our case, an extensive literature survey would be performed on existing models of the North Atlantic air system.

For the proposed model, the air traffic will be simulated from take off to landing as they travel across the North Atlantic Ocean. This should include:

1. Influences by meteorological data
2. Allow domestic and oceanic flight structures to be represented
3. Incorporate individual aircraft flight planning
4. Emulate the congestion effect or competition for optimal flight paths
5. Allow global optimization before entering clearance algorithms (user specified)
6. Provide (various) clearance actions as Air Traffic Control (ATC) operators
7. Simulate both direction of traffic with aircraft on the Organized Track System (OTS) and the more diverse random routes as well.

Further requirements of the proposed model describe the overall input and output modes of the program. For the input mode, the user will have a (user friendly) interactive menu or graphical driven system to enter the input parameters. Some of the menu choices can be duplicated from Canada Transport's model NATTAM[2] , which provides excellent menu driven interface. At this level, default values can be displayed by the user and then altered. For entry of the traffic schedule, aircraft type, and particular track settings of the day, the user will have a choice of either direct input (key entry or disk file) or random generation by the model, based on empirical data.

The output mode will provide two main channels to direct the performance information, the hard copy reports and graphical animation . The hard copy reports will create both diagnostic and summary statistics (user specified), detailing the system parameters such as :

- **Safety calculations** (lateral & longitudinal occupancy values)
- **System efficiency statistics**: fuel burn, flight time, delay times, crew costs (specified per airline per aircraft type), and clearance request statistics
- **Communication loadings** : channel loadings, frequency of message transmissions, message delay statistics
- **System capacities** : maximum verse actual track traffic loadings
- **System flexibility** : composite statistics representative of potential characteristics of system to contain costs (safety/fuel burn) at various traffic profiles (this statistic may require further definition and investigation)

The graphical animation will provide :

- Dynamic visualization of system patterns and parameters
- Dynamic charts and statistics representing the system parameters the user is interested in (some being specified by the user)
- Effective presentation to both novice and expert of the system characteristics
- Further verification of the model

The framework of the model should be designed in a modular structure for simplified expansion or modifications in the future. Borrowing the concepts of previous models, the following diagram summarizes this modular structure:

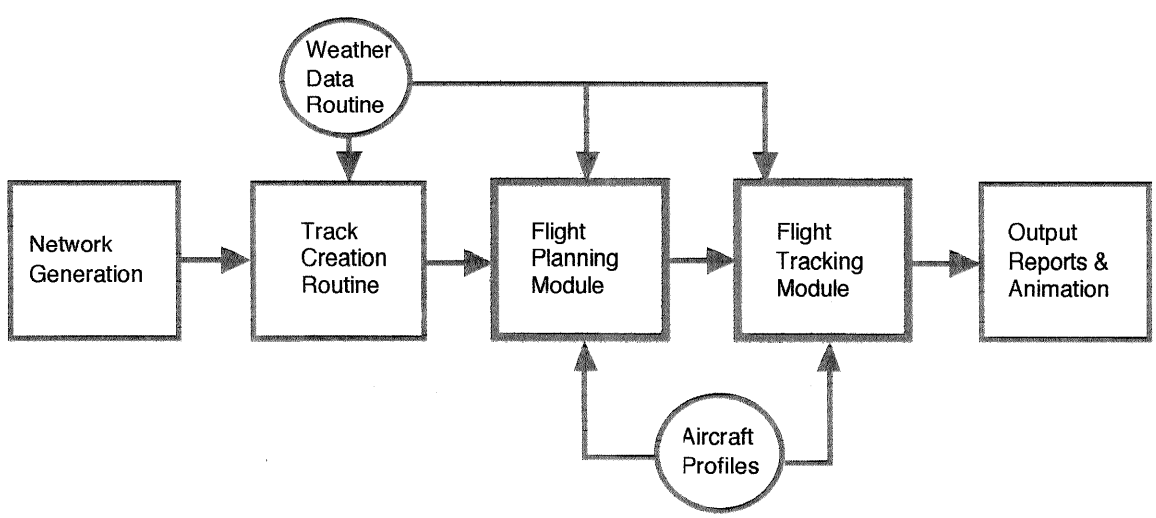

Figure 1 : Framework of Proposed Model

The two main modules are the Flight Planning and Flight Tracking. The Flight Planning Module simulates the generation of flight plans either empirically or by input files. This process will require the input from the supporting routines such as the Weather Routine, Track Creation Routine, Network Generation Module, and the aircraft profiles. An optimization algorithm will generate the flight plan for each aircraft without consideration of other aircraft in the system. These aircraft are created by direct input or a randomly generated flight schedule on an hourly interval basis. A secondary global optimization algorithm (considering all the traffic arriving) may be utilized here to provide system saving's comparison later in the models refinement.

The second main module, the Flight Tracking Module, accepts the aircraft flight plans from the previous module and determines the proper clearance, based on the input flight control strategies. These strategies may include:

- Separation standards specified by user
- Step climb or cruise climb choices
- Conflict resolution rules specified (or altered) by the user
- Conflict detection rules not included in the separation standards (specified by user)

This crucial module acts as the Air Traffic Control Center granting the actual flight plan available considering all the traffic already cleared and in the system.

As aircraft are flown through the system, statistical counters determine the cost differential between actual flight profile, planned flight profile, and free flight profile * . The other performance statistics as described earlier are continuously tallied by the GPSS schedule processor during the flight of the aircraft.

Work Accomplished To Date:

The first step taken was to perform a North Atlantic system description and literature survey of similar modeling efforts. Completed in February 1995, the main conclusions of this literature survey described the scope, basic framework, main results, and possible shortcomings of four oceanic air traffic simulation models[2] . These include the Flight Cost Model (FCM) by SRI International and the Federal Aviation Administration in 1979, the North Pacific Track System Model (NOPAC) by the Federal Aviation Administration in 1984, the North Atlantic Track Model (NATRACK) by the Civil Aviation Authority in 1988, and the North Atlantic Traffic Allocation Model (NATTAM) by Canada Transport in 1991. As stated in the Literature Survey Section 4.6[2], the following is a reprinting of the final conclusions:

1. The FCM, the most inclusive model, simulated the entire flight incorporating weather influences, routing restrictions, separation standards, and conflict

* Free flight is the theoretical unconstrained flight profile of the aircraft.

strategies. The FCM is utilized to compare fuel consumption costs from various separation configurations and traffic congestion levels. Developed in 1979, one of the major shortcomings, now in 1995, of the FCM is it modeled an oceanic system approximately 16 years old.

2. The NOPAC model simulates the entire flight of aircraft flying in the North Pacific air system. This system, different from the NAT in several ways, had a fixed track system. With a fixed track structure, the NOPAC model uses demand functions to enter tracks and monitors the flights during their crossings. The main result of the NOPAC model is the occupancy values in comparing systems in the pre- and post-composite separation modes.

3. The NATRACK model simulates aircraft crossings of Westbound traffic over the NAT. Using empirical distributions for flight requests and flight clearance algorithms based on Shanwick ATS operations, the NATRACK model evaluates both economic and safety parameters. However, weather influences and communication loadings are not considered. Also the model only simulates one direction of traffic, Westbound, and utilizes a rather small set of aircraft characteristics.

4. The NATTAM simulates aircraft crossings of the North Atlantic also. The NATTAM requires the input of the flight plans and track structure. Utilizing conflict resolution decision trees, the NATTAM tracks the aircraft flight across the NAT. The model offers users easy menus to alter system parameters and run the simulator. The model mainly determines the safety impact of alternative flight plans and parameter choices. It does provide very comprehensive alternatives, including changes to traffic concentrations to core tracks. However, the NATTAM does not provide cost output or consider weather influences and communication loadings. The model does require input for flight plans as well.

The next step following the completion of the Literature Survey and to the present, was an intensive data analysis and initial modeling of the Flight Tracking Module (described in Figure 1). The data analysis began by examining eight peak summer days of traffic data, collected by Gander Oceanic Control Center from May 15, 1993 to September 4, 1993 (refer to appendix). The analysis produced empirical distributions and statistics, including:

- Average daily traffic per track designator per hourly interval of aircraft entry times
- 1000 plus origin destination pairs present in the 8 days were categorized into 9 routings and hourly traffic of these routings were extracted
- Frequency of aircraft types
- Track coordinate statistics of each day's way point reporting points (with statistics on number of reported verse the actual number in the system per way point)
- Correlation data linking random traffic verse Eastbound/Westbound Organized Track System (OTS) traffic

The analysis provided the preliminary empirical data to proceed into modeling the Flight Tracking of the North Atlantic air traffic (refer to appendix). Based on this empirical data and the analysis described, we can now generate traffic distributions statistically identical to those found empirically.

By following an iterative process, the Flight Tracking was considered the initial scope of the model and the input system parameters as depicted in Figure 1's framework diagram was generated empirically from the 8 days of data. Specifically, the weather influences and the network generation routine were not considered and the system data attributed by the Track Setting Routine and Flight Planning Module were generated empirically. For the Track Setting Routine, program code was developed using conditional probabilities of the tracks present during the 8 days of data. For example, track F was present 7 out of the 8 days; however, track G, only present if track F was present, could be conditioned on track F's presence. Of course, this is only approximately correct, but provides an initial method to generate realistic track settings until the model scope is increased to include modeling the Track Setting Routine. For Flight Planning Module, the hourly track traffic demands were generated using discrete probability distributions from the data of the 8 days. In other words, a Flight Tracking Model is being developed first, considering it as a black box with input empirically representative of the previous modules listed in Figure 1 (refer to Figure 2 below).

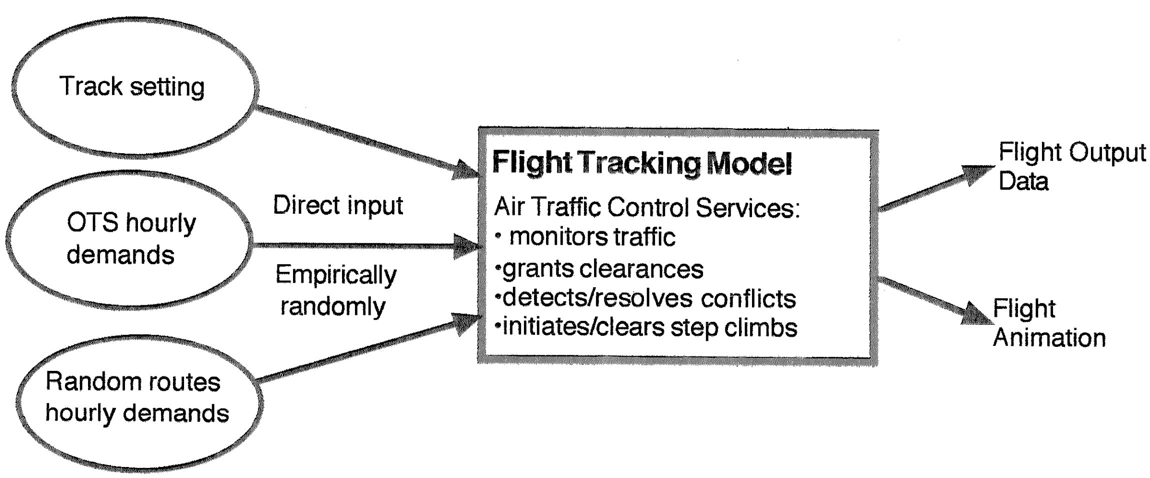

Figure 2: Initial Flight Tracking Model

Statistical tests including Chi-Squared Goodness of Fit Tests and t-Paired Confidence Intervals were employed to verify the empirical distributions. The results from these tests prove that the distributions from the data and simulated results are statistically equivalent (refer to appendix).

Currently, a flowchart of the Flight Tracking Model is being developed and programmed into GPSS. This flowchart must incorporate the two main sub-modules of the Flight Tracking Model :

1. Flight conflict detection algorithm - incorporating the actual air traffic controller rules on detecting flight conflicts and the separation standards input or defaulted into the model by the user
2. Flight conflict resolution algorithm - starting with the detailed flowcharts developed by Canada Transport's NATTAM Model[2] (based on Gander ATC) and then possible enhancement for other ATC sets of resolution rules

Once the programming is complete, model runs will be generated for intensive verification and validation.

Future Direction / Next Steps:

As discussed in section 1, the overall goal of the project is to build a credible model of the North Atlantic air traffic system. To accomplish this, we plan to follow an iterative like process by modeling each module as displayed in Figure 1, starting with the Flight Tracking Module. This evolutionary process was illustrated by Kelton and Law[1] in the following diagram (Figure 3):

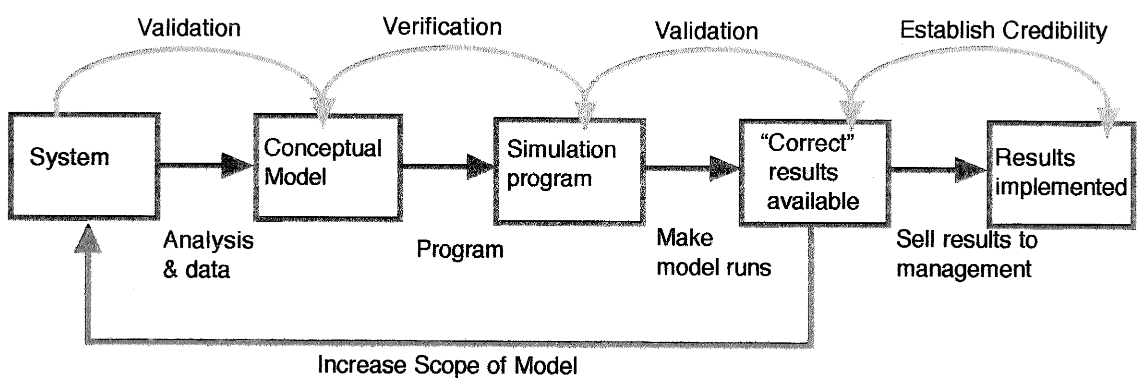

Figure 3 : Building Valid & Credible Simulation Models[1]

The immediate steps of the project are :

1. Completion of the Flight Tracking Model, verification, and validation
2. Refinement of the Flight Tracking Model, such as graphical animation output, safety, fuel burn calculations, etc.
3. Expansion of model scope, development of the Flight Planning Module, which will determine the individual aircraft flight plans or optimal flight profiles
4. Repeat the verification and validation tests, and expand the model further (incorporating the other modules from Figure 1, such as Weather Data)

References:

1. Law, Averill M., Kelton, W. David, *Simulation Modeling And Analysis*, Second Edition, McGraw-Hill, Incorporated, 1991.
2. Paglione, M., Elsayed, E. A. , "Modeling of the Air Traffic Activity Over the North Atlantic Ocean: Literature Survey and System Description", Rutgers University Department of Industrial Engineering, 1995.